Year: 2019

Posterior Acromial Morphology Is Significantly Associated with Posterior Shoulder Instability

Meyer, Dominik C ; Ernstbrunner, Lukas ; Boyce, Glenn ; Imam, Mohamed A ; El Nashar, Rany ; Gerber, Christian

Abstract: BACKGROUND The purpose of this paper was to determine whether acromial morphology influences anteroposterior shoulder stability. We hypothesized that a more horizontal and higher position of the acromion in the sagittal plane would be associated with posterior instability. METHODS In this retrospective study, patients with unidirectional posterior instability were age and sex-matched to a cohort of patients with unidirectional anterior instability. Both cohorts were compared with a control group of patients with no instability and no degenerative glenohumeral (rotator cuff and/or joint surface) or acromial changes. Measurements on radiographs included posterior acromial tilt, anterior and posterior acromial coverage (AAC and PAC), posterior acromial height (PAH), and the critical shoulder angle (CSA). RESULTS The number of patients enrolled in each instability group was 41, based on a priori power analysis. The control group consisted of 53 shoulders. Of the measured anatomic factors, PAH showed the most significant association with posterior instability (odds ratio [OR] = 1.8; $p < 0.001$) in the logistic regression model. PAH was significantly greater in the posterior instability group compared with the anterior instability group (30.9 versus 19.5 mm; $p < 0.001$). With a cutoff value of PAH of 23 mm, the OR for posterior instability was 39. Shoulders with posterior instability were also significantly different from normal shoulders with regard to PAH ($p < 0.001$), AAC ($p < 0.001$), and PAC ($p < 0.001$) whereas, in the shoulders with anterior instability, all of these values except the AAC ($p = 0.011$) did not differ from those of normal shoulders. CONCLUSIONS Specific acromial morphology is significantly associated with the direction of glenohumeral instability. In shoulders with posterior instability, the acromion is situated higher and is oriented more horizontally in the sagittal plane than in normal shoulders and those with anterior instability; this acromial position may provide less osseous restraint against posterior humeral head translation. A steep ”Swiss chalet roof-type” acromion virtually excluded recurrent posterior instability in an albeit relatively small cohort of patients. Additional investigation is needed to determine the relevance of these findings for future treatment. LEVEL OF EVIDENCE Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

DOI: https://doi.org/10.2106/JBJS.18.00541

Meyer, Dominik C; Ernstbrunner, Lukas; Boyce, Glenn; Imam, Mohamed A; El Nashar, Rany; Gerber, Christian (2019). Posterior Acromial Morphology Is Significantly Associated with Posterior Shoulder Instability. Journal Bone Joint Surgery America, 101(14):1253-1260.
DOI: https://doi.org/10.2106/JBJS.18.00541

Posterior Acromial Morphology Is Significantly Associated with Posterior Shoulder Instability

Dominik C. Meyer, MD,* Lukas Ernstbrunner, MD,* Glenn Boyce, MD, Mohamed A. Imam, MD, Rany El Nashar, MD, and Christian Gerber, MD

Investigation performed at the Division of Shoulder and Elbow Surgery, Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Switzerland

Background: The purpose of this paper was to determine whether acromial morphology influences anteroposterior shoulder stability. We hypothesized that a more horizontal and higher position of the acromion in the sagittal plane would be associated with posterior instability.

Methods: In this retrospective study, patients with unidirectional posterior instability were age and sex-matched to a cohort of patients with unidirectional anterior instability. Both cohorts were compared with a control group of patients with no instability and no degenerative glenohumeral (rotator cuff and/or joint surface) or acromial changes. Measurements on radiographs included posterior acromial tilt, anterior and posterior acromial coverage (AAC and PAC), posterior acromial height (PAH), and the critical shoulder angle (CSA).

Results: The number of patients enrolled in each instability group was 41, based on a priori power analysis. The control group consisted of 53 shoulders. Of the measured anatomic factors, PAH showed the most significant association with posterior instability (odds ratio [OR] = 1.8; $p < 0.001$) in the logistic regression model. PAH was significantly greater in the posterior instability group compared with the anterior instability group (30.9 versus 19.5 mm; $p < 0.001$). With a cutoff value of PAH of 23 mm, the OR for posterior instability was 39. Shoulders with posterior instability were also significantly different from normal shoulders with regard to PAH ($p < 0.001$), AAC ($p < 0.001$), and PAC ($p < 0.001$) whereas, in the shoulders with anterior instability, all of these values except the AAC ($p = 0.011$) did not differ from those of normal shoulders.

Conclusions: Specific acromial morphology is significantly associated with the direction of glenohumeral instability. In shoulders with posterior instability, the acromion is situated higher and is oriented more horizontally in the sagittal plane than in normal shoulders and those with anterior instability; this acromial position may provide less osseous restraint against posterior humeral head translation. A steep "Swiss chalet roof-type" acromion virtually excluded recurrent posterior instability in an albeit relatively small cohort of patients. Additional investigation is needed to determine the relevance of these findings for future treatment.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Recurrent posterior glenohumeral instability has been associated with increased glenoid retroversion and dysplasia of the posteroinferior aspect of the glenoid rim[1-3]. Anterior glenohumeral instability has been found to be associated not only with anterior glenoid bone loss[4-6] but also with deficient depth of the glenoid concavity[7,8]. The relationship of acromial anatomy to glenohumeral stability has not been studied, to our knowledge. The only information on this topic that we found in the literature was in the study by Scapinelli[9], who indirectly suggested that the posterior aspect of the acromion could play a role in recurrent posterior shoulder instability by proposing grafting of the posterolateral aspect of the acromion to lend better mechanical support to the posterior aspect.

*Dominik C. Meyer, MD, and Lukas Ernstbrunner, MD, contributed equally to this article.

Disclosure: The authors indicated that no external funding was received for any aspect of this work. On the **Disclosure of Potential Conflicts of Interest** forms, *which are provided with the online version of the article*, one or more of the authors checked "yes" to indicate that the author had a relevant financial relationship in the biomedical arena outside the submitted work (http://links.lww.com/JBJS/F344).

In addition to specific acromial anatomy in the coronal plane in patients with osteoarthritis or a rotator cuff tear[10-17], we have observed that, in the sagittal plane, a relatively horizontally oriented acromion that is situated very high with respect to the center of the humeral head seems to be associated with recurrent posterior glenohumeral instability. It was therefore the purpose of this study to investigate whether stable and unstable shoulders are associated with different acromial morphology in the sagittal plane and to specifically test the hypothesis that recurrent posterior instability is associated with a more horizontal and higher position of the acromion in the sagittal plane than in stable shoulders or those with recurrent anterior instability.

Materials and Methods

Study Population

After the responsible investigational review board granted approval for this retrospective study, we identified a consecutive series of 41 shoulders surgically treated for unidirectional, recurrent posterior shoulder instability. This posterior instability group was then case-matched by age (within 5 years) and sex to 41 patients with surgically treated unidirectional, recurrent anterior instability. The instability was involuntary in all cases. A positive physical examination for posterior instability was defined as a positive jerk[18] and/or posterior apprehension test[19]. A positive physical examination for anterior instability was defined as a positive apprehension test and a positive hyperabduction test[20]. Recurrence was defined as repeated episodes of instability associated with positive physical findings for recurrent anterior or posterior instability[20]. Subluxation was defined as the subjective sensation of the humerus slipping out of the joint followed by spontaneous reduction[21]. Specific intraoperative findings confirmed unidirectional anterior or posterior instability.

Inclusion criteria were an age younger than 40 years, availability of serial radiographs including anteroposterior and true lateral (supraspinatus outlet or Neer[22]) views made under fluoroscopic control as well as a computed tomography (CT) scan of the shoulder, and symptomatic unidirectional instability. Patients were excluded (n = 17) if they had had previous bone block procedures, chronic dislocation, glenoid fracture, seizures, glenoid bone loss of >20% as measured with the Pico method[23,24], an engaging Hill-Sachs lesion (as confirmed intraoperatively), glenoid dysplasia according to the Weishaupt classification[2], glenoid retroversion of >15°[25], multidirectional instability according to the Gerber classification[26], hyperlaxity according to the Beighton criteria[27], skeletal dysplasia, or a connective-tissue disorder.

There were 25 male and 16 female patients in each of the 2 instability groups. The mean age was 27 years (range, 15 to 39 years) in the posterior instability group and 26 years (range, 14 to 39 years) in the anterior instability group. All patients had an initial traumatic injury in the anterior instability group whereas 14 patients (34%) did in the posterior instability group.

In addition, 66 consecutive orthopaedic patients who were treated for a pathological disorder not involving the shoulder joint served as controls. All of these patients had asymptomatic shoulders and no history of surgery or pathological involvement of the shoulder and all underwent ultrasound, performed by an independent radiologist, on each shoulder to assess rotator cuff integrity. Conventional radiographs were made to exclude any degenerative changes in the glenohumeral joint or at the acromion in the controls. As opposed to conventional radiography and ultrasound examination, CT scanning had not been approved by the institutional review board for these asymptomatic shoulders. Thirteen patients with either signs of early glenohumeral arthritis according to the criteria described by Samilson and Prieto[28] or partial or full-thickness tears of the rotator cuff as diagnosed with ultrasound were excluded. Therefore, the control group consisted of 53 shoulders of 53 patients (27 female) without instability or degenerative glenohumeral (rotator cuff and/or joint surface) or acromial changes. The mean age of the control group was 65 years (range, 60 to 73 years). A distinctly higher age in a control group with stable and asymptomatic shoulders was necessary to be certain to have excluded patients with a late onset of instability.

Radiographic Evaluation

Two blinded observers (orthopaedic surgeons trained in shoulder surgery) performed all measurements on radiographs, which were available and of suitable quality for all shoulders in

Fig. 1

Posterior acromial tilt is determined by measuring the angle formed by the reference line (connecting the inferior angle of the scapula with the center of the intersection of the small arms of the "Y") and a line connecting the most posterior point of the inferior aspect of the acromion to the most anterior point of the inferior aspect (white area).

all 3 groups. True lateral radiographs were determined to be suitable if the coracoid process and scapular spine appeared as symmetric upper limbs of a "Y" with the humeral head not overlying the supraspinatus outlet region and the central beam was in line with the supraspinatus fossa. All Y views had been obtained under fluoroscopic control.

The posterior angle of the acromion was identified on the conventional true lateral radiographs. A line connecting the inferior angle of the scapula with the center of the intersection of the small arms of the "Y" (the coracoid and scapular spine) was defined as the reference line for each measurement on the true lateral radiographs. The posterior slope (or posterior acromial tilt) was measured as the angle between the reference line and a line connecting the most posterior point of the inferior aspect of the acromion (posterior intersection of the inferior and superior sclerotic lines) to the most anterior point of the inferior aspect of the acromion (anterior intersection of the inferior and superior sclerotic lines) (Fig. 1). To measure the relationship of the posterior acromial overhang to the glenoid, anterior and posterior acromial coverage (AAC and PAC) were determined by measuring the angle between the reference line and a line drawn from the intersection of the small arms of the "Y" to the most anterior point of the inferior aspect of the acromion (AAC) or a line drawn from the intersection to the most posterior point of the inferior aspect of the acromion (PAC), respectively (Figs. 2-A and 2-B). An AAC anterior to the reference line was defined as a negative angle. The relationship between the height of the posterior aspect of the acromion and the glenoid was determined by drawing a perpendicular line from the reference line to the most posterior point of the inferior aspect of the acromion. The distance from the center of the intersection of the small arms of the "Y" to this perpendicular line was determined to be the posterior acromial height (PAH) (Fig. 3). On anteroposterior views, the critical shoulder angle (CSA) was measured as previously described by Moor et al.[12,14,15,17,29].

CT scans were available for all unstable shoulders but not for the stable, normal shoulders. Some CT studies were available in an electronic format whereas others were printed images not suitable for 3-dimensional (3-D) reconstruction. Because spatial orientation of the scapula affects the results of 2-D measurements on CT[30,31], CT scans that cannot be 3-D-reconstructed have not proven to yield substantially better information than standardized lateral radiographs. Thus, in the absence of CT studies for the control group and the lack of 3-D-reconstructible CT scans for some of the unstable shoulders, we

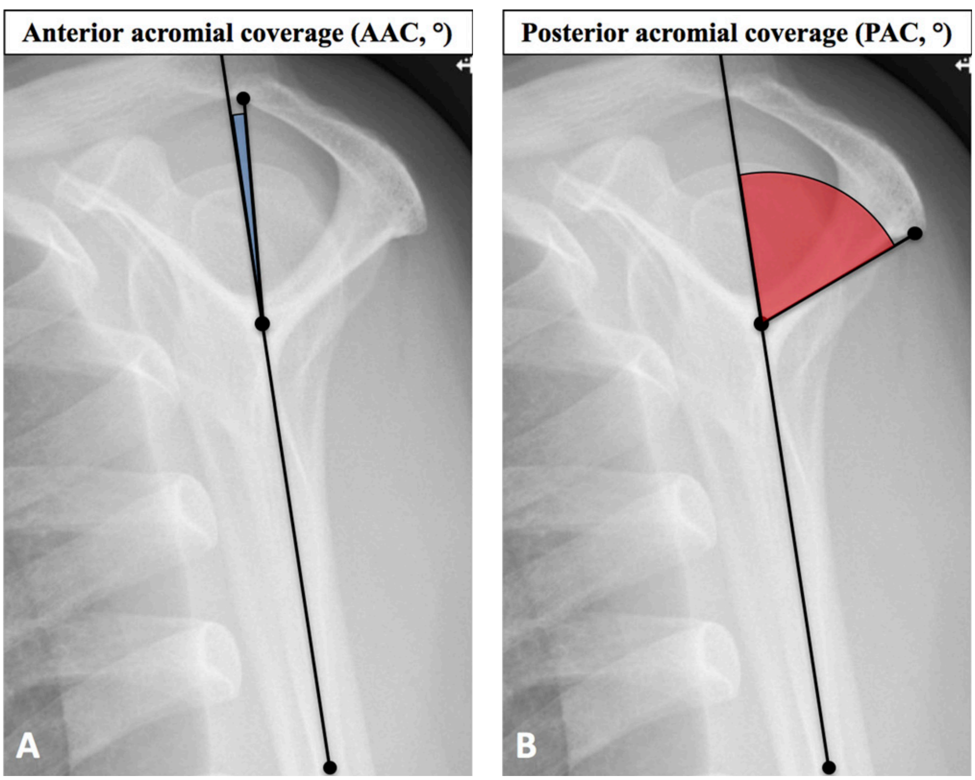

Fig. 2-A Fig. 2-B

Fig. 2-A The AAC refers to an angle formed by the reference line (connecting the inferior angle of the scapula with the center of the intersection of the small arms of the "Y") and a line drawn from the intersection of the small arms of the "Y" to the most anterior point of the inferior aspect of the acromion (blue area). **Fig. 2-B** The PAC refers to an angle formed by the reference line (connecting the inferior angle of the scapula with the center of the intersection of the small arms of the "Y") and a line drawn from the intersection of the small arms of the "Y" to the most posterior point of the inferior aspect of the acromion (red area).

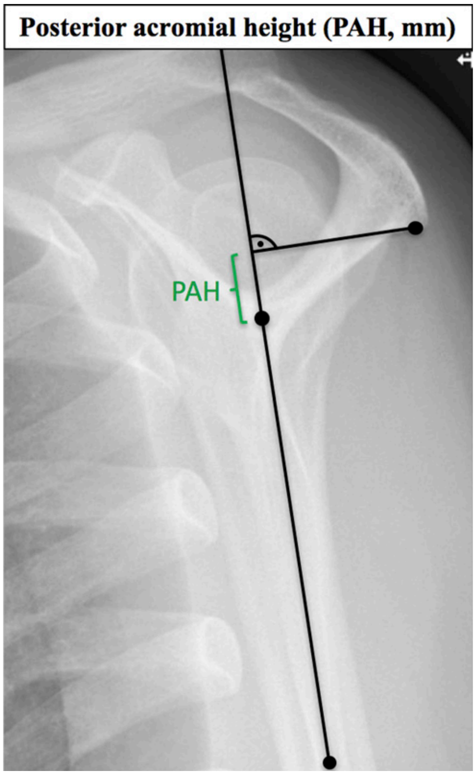

Fig. 3
To measure the PAH, a perpendicular line is drawn from the reference line (connecting the inferior angle of the scapula with the center of the intersection of the small arms of the "Y") to the most posterior point of the inferior aspect of the acromion. The PAH (green bracket) is then measured as the distance from the center of the intersection of the small arms of the "Y" to the perpendicular line.

used the universally available true lateral radiographs made with the highly standardized technique outlined above.

Statistical Methods

On the basis of previously published data concerning posterior acromial tilt[32], an a priori power analysis revealed that, for a significance level of 0.05 (type-I error), a sample size of 41 patients in each instability group was sufficient to provide a desired power of 80% to determine significant differences in posterior acromial tilt.

The posterior and anterior instability groups were matched according to their age (within 5 years) and sex (FUZZY extension, SPSS Statistics, version 24; IBM). Means and standard deviations of continuous variables were calculated. Data were assessed for normality with the Shapiro-Wilk test. Normally distributed data were compared using the paired t test (matched-pair analysis of posterior versus anterior instability group) and with the unpaired t test (comparison of the control group and each instability group). Non-normally distributed data were compared using the Wilcoxon signed rank test (matched pair analysis of posterior versus anterior instability group) and with the Mann-Whitney U-test (comparison of the control group and each instability group). A logistic regression analysis was conducted on all measured anatomic factors to determine the most significant association with the outcome variable (direction of instability). Odds ratios (ORs) are presented with 95% confidence intervals (CIs). The goodness of fit of the binary logistic regression models was assessed via the Hosmer-Lemeshow test. Adjustments for possible confounders were not performed as the instability groups were a priori age and sex-matched. Receiver operating characteristic (ROC) curves were performed to determine cutoff values for the measured anatomic factors that most significantly influenced the regression model. Significance was set as $p < 0.05$, and all p values were 2-tailed.

Interobserver reliability was measured for posterior acromial tilt, AAC, PAC, PAH, and CSA by means of the intraclass correlation coefficient (ICC) for absolute agreement, with 1 indicating perfect reliability.

Results

Interobserver reliability was either excellent or very good for posterior acromial tilt (r = 0.93; 95% CI = 0.87 to 0.96), AAC (r = 0.89; 95% CI = 0.81 to 0.94), PAC (r = 0.86; 95% CI = 0.76 to 0.93), PAH (r = 0.87; 95% CI = 0.76 to 0.93), and CSA (r = 0.84; 95% CI = 0.70 to 0.91).

TABLE I Comparison of Posterior Acromial Morphology Between Posterior and Anterior Instability Groups*

Variable	Mean and Standard Deviation: Posterior Instability (N = 41)	Mean and Standard Deviation: Anterior Instability (N = 41)	Absolute Value of Difference	OR† (95% CI)	P Value‡
PAH *(mm)*	30.9 ± 6.7	19.5 ± 8.5	11.4	1.8 (1.2-2.7)	<0.001
AAC *(°)*	−8.8 ± 8.6	2.9 ± 7.6	−11.7	1.4 (1.1-1.9)	<0.001
PAC *(°)*	48.8 ± 8.5	60.9 ± 11.6	−12.1	1.1 (1.1-1.4)	<0.001
Posterior acromial tilt *(°)*	63.6 ± 9.8	55.8 ± 8.0	7.8	1.1 (1.1-1.3)	0.001
CSA *(°)*	32.1 ± 4.9	30.1 ± 4.5	2.0	NS	NS

*NS = not significant (p > 0.05). †The ORs were calculated with logistic regression analysis. ‡The p values are based on the matched-pair analysis with the paired t test (normal distribution) and the Wilcoxon signed rank test (non-normal distribution).

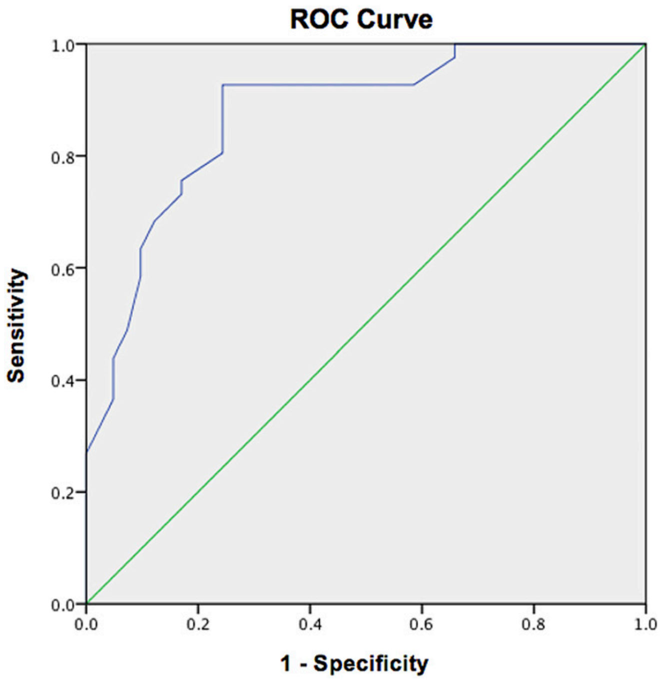

Fig. 4
ROC curve (blue line) to determine the cutoff value of PAH for discriminating between posterior and anterior instability. The reference line is indicated in green. The area under the curve was 0.875.

Posterior Versus Anterior Instability

Patients with posterior instability had a significantly greater mean PAH compared with those with anterior instability (30.9 versus 19.5 mm; $p < 0.001$). Of the measured anatomic factors, the PAH (OR = 1.8; 95% CI = 1.2 to 2.7; $p < 0.001$) showed the most significant association with posterior instability in the logistic regression model. Data on the other anatomic factors are depicted in Table I.

ROC curve analysis for the factor with the most significant association (PAH) determined a cutoff value of 23 mm for discriminating between posterior and anterior instability (Fig. 4). The area under the curve was 0.875 and the OR for developing posterior instability with a PAH of >23 mm was 39 (95% CI = 10 to 155; $p < 0.001$).

Posterior Instability Versus Control Group

Patients with posterior instability had a significantly greater mean PAH (30.9 versus 20.4 mm; $p < 0.001$) and posterior acromial tilt (63.6° versus 55.9°; $p < 0.001$) compared with the control group. The mean AAC (−8.8° versus −1.5°) and PAC (48.8° versus 61.6°) were significantly lower in the posterior instability group (both comparisons $p < 0.001$) than in the control group. The mean CSA did not differ significantly between the groups (32.1° versus 33.3°; $p = 0.184$).

In the logistic regression model, posterior instability showed a significant association with PAH (OR = 1.2; 95% CI = 1.1 to 1.4; $p < 0.001$), AAC (OR = 1.1; 95% CI = 1.1 to 1.2; $p < 0.001$), PAC (OR = 1.1; 95% CI = 1.1 to 1.2; $p < 0.001$), and posterior acromial tilt (OR = 1.1; 95% CI = 1.1 to 1.2; $p < 0.001$). The Hosmer-Lemeshow test confirmed goodness of fit of the model ($p = 0.593$).

With a cutoff value of 23 mm for PAH, the OR for developing posterior instability compared with the control group was 32 (95% CI = 9 to 120; $p < 0.001$).

Anterior Instability Versus Control Group

Patients with anterior instability had a significantly greater mean AAC (2.9° versus −1.5°; $p = 0.011$) and lower CSA (30.1° versus 33.3°; $p < 0.001$) compared with the control group. There were no significant differences between the 2 groups regarding mean posterior acromial tilt (55.8° versus 55.9°; $p = 0.729$), PAC (60.9° versus 61.6°; $p = 0.336$), or PAH (19.5 versus 20.4 mm; $p = 0.594$).

The logistic regression model showed a significant association between anterior instability and the CSA (OR = 1.3; 95% CI = 1.1 to 1.4; $p = 0.001$) and AAC (OR = 1.2; 95% CI = 1.1 to 1.3; $p = 0.011$). The Hosmer-Lemeshow test confirmed goodness of fit of the model ($p = 0.522$).

Discussion

Previous reports have shown that glenoid version and morphology are correlated with the presence or absence of glenohumeral stability[1,7,8,33].

This study demonstrates a significant association between instability and acromial anatomy, mostly in the sagittal plane. The strongest predictive factor for posterior instability among those that we studied was posterior acromial morphology. The new information from this study is that a higher and more horizontally oriented acromion is strongly associated with recurrent posterior shoulder instability and that a steep acromion ("Swiss chalet roof configuration") virtually excluded shoulders from the posterior instability group, albeit in a relatively small cohort of patients (Figs. 5-A and 5-B).

In our series, PAH showed the most significant association with posterior instability and was the parameter that differed the most between the posterior and anterior instability groups. The most distinguishing cutoff value for posterior instability was a PAH of >23 mm, which resulted in an OR of 39 for posterior instability. The posterior acromial morphology of the posterior instability group was also different from that of the normal shoulders. Conversely, there was no difference in posterior acromial morphology between the normal shoulders and those with anterior instability. Biomechanical studies seem warranted to explain these clinical findings.

In this study, all patients with anterior instability reported a traumatic event causing the first dislocation whereas only 34% (14) of the patients with posterior instability did. The fact that a traumatic event is not necessary for the development of symptoms of posterior instability is compatible with a much more important mechanical predisposition to posterior instability than to anterior instability. It is conceivable that, if the osseous restraints created by the posterior aspect of the acromion are lacking, recurrent posterior instability starts relatively early in life, without trauma or clinical symptoms, after which the posterior capsular restraints soon become overloaded, resulting in clinically apparent posterior instability. Gottschalk et al.[1] found

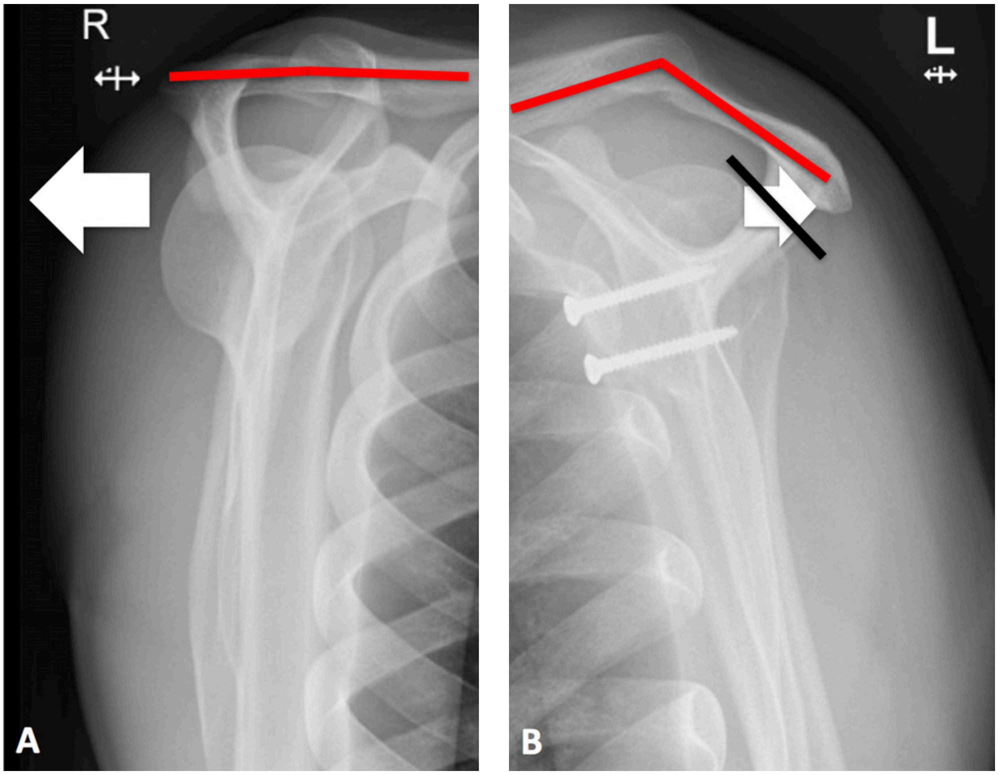

Fig. 5-A

Fig. 5-B

Fig. 5-A Typical radiograph of a patient with posterior instability (arrow), showing the high-riding and flat acromion (red line, “flat roof configuration”). **Fig. 5-B** Typical radiograph of a patient with anterior instability, with posterior osseous coverage of the humeral head (red line, “Swiss chalet roof configuration”) restricting posterior translation (arrow).

that patients with posterior instability had a significantly higher rate of contralateral surgery for posterior instability than those with anterior instability. This could be explained by a more important role of anatomic factors if such factors were found in these cases and if they could be shown to be generally bilateral.

Our study had both strengths and limitations. A strength is that we included the required number of shoulders as indicated by our a priori power analysis. Furthermore, we validated our results by comparing them with those in patients without any pathological involvement of the shoulder as confirmed by clinical examination, radiographs, and ultrasound.

With regard to limitations, there is some inaccuracy when measuring 3-D structures using 2-D imaging even when the 2-D imaging is fluoroscopically controlled. This was evidenced by a decreasing correlation coefficient if different radiographs of the same patient were analyzed. There is a need for future studies employing 3-D analysis, but the very large differences between findings in the posterior instability group and those in the anterior instability and control groups justify the use of the current data, which were generated in a very standardized fashion.

The retrospective nature of this study is also a potential weakness. However, with the rarity of isolated posterior instability, a prospective research model is probably not feasible. The systematic, standardized collection of clinical and radiographic data for all patients undergoing treatment for shoulder conditions in our institution provided a possibly not optimal but robust basis for our study. Matching the instability groups to reduce the influence of sex and age on the direction of instability appears to further minimize potential confounding factors. Another limitation is that we did not include the influence of glenoid bone loss or other pathological disorders on the humeral side, but humeral head pathology is rare in recurrent posterior subluxations and, like minor glenoid rim changes, does not influence the measurements reported[2,34,35].

It would have been highly desirable to have had a perfectly matched control group, and we acknowledge that the significantly older age of the control group is a problem. However, to determine whether shoulders with anterior or posterior instability have different mechanical conditions defined by the orientation, shape, and position of the acromion compared with “normal” shoulders, we needed to identify controls with shoulders that had no degenerative joint surface or rotator cuff changes and that specifically and definitely had no instability. The development of instability cannot be excluded until well after the age of 40 years. Therefore, an age-matched control group would have been invalidated by the argument that we could not know whether the patients in that group would ultimately develop instability. With extremely strict inclusion and exclusion criteria, we excluded acromial changes secondary to any degenerative or traumatic changes as well as genetically dysplastic shoulders. As posterior instability was found to be associated with a particular acromial position and morphology that are significantly different from those of "normal" shoulders, we believe that the findings in the control group are an important prerequisite for future studies.

Despite the limitations, this study does document, for the first time to our knowledge, that there is a strong association between acromial morphology and the direction of glenohumeral instability, specifically recurrent posterior instability. The study furthermore highlights that acromial morphology needs to be taken into account and studied further, especially to better understand and possibly improve treatment of recurrent posterior instability. Whether ultimately the association of posterior acromial morphology with posterior instability will be relevant to treatment is unclear. Scapinelli[9] described a technique to provide more posterior osseous restraint against posterior instability by grafting the posterior aspect of the acromion with a bone block. The bone block was placed to exert slight pressure on the infraspinatus, but it was not clear why more overhanging of the acromion improved stability. Whether such a form of treatment holds promise will need to be studied experimentally and, if successful in that setting, clinically.

Conclusions

Specific acromial morphology is significantly associated with the direction of glenohumeral instability. In patients with posterior instability, the acromion is situated higher and is oriented more horizontally in the sagittal plane, which may provide less osseous restraint against posterior humeral head translation. A steep acromion ("Swiss chalet roof configuration") virtually excluded recurrent posterior instability in an albeit relatively small cohort of patients in our study. Additional investigation is needed to determine the relevance of these findings for future treatment. ■

Dominik C. Meyer, MD[1]
Lukas Ernstbrunner, MD[1]
Glenn Boyce, MD[1]
Mohamed A. Imam, MD[1]
Rany El Nashar, MD[1]
Christian Gerber, MD[1]

[1]Division of Shoulder and Elbow Surgery, Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Switzerland

E-mail address for L. Ernstbrunner: lukas.ernstbrunner@balgrist.ch

ORCID iD for D.C. Meyer: 0000-0002-7154-7201
ORCID iD for L. Ernstbrunner: 0000-0003-4920-8518
ORCID iD for G. Boyce: 0000-0001-5123-8340
ORCID iD for M.A. Imam: 0000-0002-3646-809X
ORCID iD for R. El Nashar: 0000-0001-7176-7266
ORCID iD for C. Gerber: 0000-0002-4624-8285

References

1. Gottschalk MB, Ghasem A, Todd D, Daruwalla J, Xerogeanes J, Karas S. Posterior shoulder instability: does glenoid retroversion predict recurrence and contralateral instability? Arthroscopy. 2015 Mar;31(3):488-93. Epub 2014 Dec 10.

2. Weishaupt D, Zanetti M, Nyffeler RW, Gerber C, Hodler J. Posterior glenoid rim deficiency in recurrent (atraumatic) posterior shoulder instability. Skeletal Radiol. 2000 Apr;29(4):204-10.

3. Hurley JA, Anderson TE, Dear W, Andrish JT, Bergfeld JA, Weiker GG. Posterior shoulder instability. Surgical versus conservative results with evaluation of glenoid version. Am J Sports Med. 1992 Jul-Aug;20(4):396-400.

4. Ernstbrunner L, Plachel F, Heuberer P, Pauzenberger L, Moroder P, Resch H, Anderl W. Arthroscopic versus open iliac crest bone grafting in recurrent anterior shoulder instability with glenoid bone loss: a computed tomography-based quantitative assessment. Arthroscopy. 2018 Feb;34(2):352-9.

5. Itoi E, Lee SB, Berglund LJ, Berge LL, An KN. The effect of a glenoid defect on anteroinferior stability of the shoulder after Bankart repair: a cadaveric study. J Bone Joint Surg Am. 2000 Jan;82(1):35-46.

6. Yamamoto N, Itoi E, Abe H, Kikuchi K, Seki N, Minagawa H, Tuoheti Y. Effect of an anterior glenoid defect on anterior shoulder stability: a cadaveric study. Am J Sports Med. 2009 May;37(5):949-54. Epub 2009 Mar 4.

7. Ernstbrunner L, Werthel JD, Hatta T, Thoreson AR, Resch H, An KN, Moroder P. Biomechanical analysis of the effect of congruence, depth and radius on the stability ratio of a simplistic 'ball-and-socket' joint model. Bone Joint Res. 2016 Oct;5(10):453-60.

8. Moroder P, Ernstbrunner L, Pomwenger W, Oberhauser F, Hitzl W, Tauber M, Resch H, Moroder R. Anterior shoulder instability is associated with an underlying deficiency of the bony glenoid concavity. Arthroscopy. 2015 Jul;31(7):1223-31. Epub 2015 Apr 7.

9. Scapinelli R. Posterior addition acromioplasty in the treatment of recurrent posterior instability of the shoulder. J Shoulder Elbow Surg. 2006 Jul-Aug;15(4):424-31.

10. Blonna D, Giani A, Bellato E, Mattei L, Caló M, Rossi R, Castoldi F. Predominance of the critical shoulder angle in the pathogenesis of degenerative diseases of the shoulder. J Shoulder Elbow Surg. 2016 Aug;25(8):1328-36. Epub 2016 Feb 15.

11. Daggett M, Werner B, Collin P, Gauci MO, Chaoui J, Walch G. Correlation between glenoid inclination and critical shoulder angle: a radiographic and computed tomography study. J Shoulder Elbow Surg. 2015 Dec;24(12):1948-53. Epub 2015 Sep 6.

12. Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint?: A radiological study of the critical shoulder angle. Bone Joint J. 2013 Jul;95-B(7):935-41.

13. Moor BK, Röthlisberger M, Müller DA, Zumstein MA, Bouaicha S, Ehlinger M, Gerber C. Age, trauma and the critical shoulder angle accurately predict supraspinatus tendon tears. Orthop Traumatol Surg Res. 2014 Sep;100(5):489-94. Epub 2014 Jul 8.

14. Moor BK, Wieser K, Slankamenac K, Gerber C, Bouaicha S. Relationship of individual scapular anatomy and degenerative rotator cuff tears. J Shoulder Elbow Surg. 2014 Apr;23(4):536-41. Epub 2014 Jan 28.

15. Nyffeler RW, Werner CM, Sukthankar A, Schmid MR, Gerber C. Association of a large lateral extension of the acromion with rotator cuff tears. J Bone Joint Surg Am. 2006 Apr;88(4):800-5.

16. Spiegl UJ, Horan MP, Smith SW, Ho CP, Millett PJ. The critical shoulder angle is associated with rotator cuff tears and shoulder osteoarthritis and is better assessed with radiographs over MRI. Knee Surg Sports Traumatol Arthrosc. 2016 Jul;24(7):2244-51. Epub 2015 Mar 29.

17. Bhatia DN, Debeer JF, Toit DF. Association of a large lateral extension of the acromion with rotator cuff tears. J Bone Joint Surg Am. 2006 Aug;88(8):1889; author reply 1889-90.

18. Kim SH, Park JC, Park JS, Oh I. Painful jerk test: a predictor of success in nonoperative treatment of posteroinferior instability of the shoulder. Am J Sports Med. 2004 Dec;32(8):1849-55.

19. Wirth MA, Groh GI, Rockwood CA Jr. Capsulorrhaphy through an anterior approach for the treatment of atraumatic posterior glenohumeral instability with multidirectional laxity of the shoulder. J Bone Joint Surg Am. 1998 Nov;80(11):1570-8.

20. Zimmermann SM, Scheyerer MJ, Farshad M, Catanzaro S, Rahm S, Gerber C. Long-term restoration of anterior shoulder stability: a retrospective analysis of arthroscopic Bankart repair versus open Latarjet procedure. J Bone Joint Surg Am. 2016 Dec 7;98(23):1954-61.

21. Blazina ME, Satzmann JS. Recurrent anterior subluxation of the shoulder in athletes - a distinct entity. J Bone Joint Surg Am. 1969;51(5):1037-8.

22. Neer CS 2nd, Poppen NK. Supraspinatus outlet. Orthop Trans. 1987;11:234.

23. Baudi P, Righi P, Bolognesi D, Rivetta S, Rossi Urtoler E, Guicciardi N, Carrara M. How to identify and calculate glenoid bone deficit. Chir Organi Mov. 2005 Apr-Jun;90(2):145-52.

24. Magarelli N, Milano G, Sergio P, Santagada DA, Fabbriciani C, Bonomo L. Intra-observer and interobserver reliability of the 'Pico' computed tomography method for quantification of glenoid bone defect in anterior shoulder instability. Skeletal Radiol. 2009 Nov;38(11):1071-5. Epub 2009 May 24.

25. Walch G, Ascani C, Boulahia A, Nové-Josserand L, Edwards TB. Static posterior subluxation of the humeral head: an unrecognized entity responsible for glenohumeral osteoarthritis in the young adult. J Shoulder Elbow Surg. 2002 Jul-Aug;11(4):309-14.

26. Gerber C, Nyffeler RW. Classification of glenohumeral joint instability. Clin Orthop Relat Res. 2002 Jul;400:65-76.

27. Beighton P. Hypermobility scoring. Br J Rheumatol. 1988 Apr;27(2):163.

28. Samilson RL, Prieto V. Dislocation arthropathy of the shoulder. J Bone Joint Surg Am. 1983 Apr;65(4):456-60.

29. Gerber C, Catanzaro S, Betz M, Ernstbrunner L. Arthroscopic correction of the critical shoulder angle through lateral acromioplasty: a safe adjunct to rotator cuff repair. Arthroscopy. 2018 Mar;34(3):771-80.

30. Bokor DJ, O'Sullivan MD, Hazan GJ. Variability of measurement of glenoid version on computed tomography scan. J Shoulder Elbow Surg. 1999 Nov-Dec;8(6):595-8.

31. Nyffeler RW, Jost B, Pfirrmann CW, Gerber C. Measurement of glenoid version: conventional radiographs versus computed tomography scans. J Shoulder Elbow Surg. 2003 Sep-Oct;12(5):493-6.

32. Balke M, Liem D, Greshake O, Hoeher J, Bouillon B, Banerjee M. Differences in acromial morphology of shoulders in patients with degenerative and traumatic supraspinatus tendon tears. Knee Surg Sports Traumatol Arthrosc. 2016 Jul;24(7):2200-5. Epub 2014 Dec 30.

33. Hohmann E, Tetsworth K. Glenoid version and inclination are risk factors for anterior shoulder dislocation. J Shoulder Elbow Surg. 2015 Aug;24(8):1268-73. Epub 2015 May 7.

34. Bigliani LU, Pollock RG, McIlveen SJ, Endrizzi DP, Flatow EL. Shift of the posteroinferior aspect of the capsule for recurrent posterior glenohumeral instability. J Bone Joint Surg Am. 1995 Jul;77(7):1011-20.

35. Pollock RG, Bigliani L. Recurrent posterior shoulder instability. 1st ed. Warner JP, Iannotti JP, Gerber C, editors. Philadelphia: Lippincott-Raven; 1997.